APPARATUS OF GENERATING GLOW PLASMA ON A WIDE SURFACE UNDER ATMOSPHERIC PRESSURE

Technical Field

The present invention relates to a plasma generation apparatus, and more particularly, to an apparatus of generating glow plasma on a wide surface under atmospheric pressure, which can provide stable glow discharge plasma at a normal temperature under atmospheric pressure.

Background Art

Plasma is an ionized gas composed of particles, which can easily go over energy barriers of gas, liquid, and solid, cut off the chain of an atom or a molecular, and combine new molecules and atoms. Accordingly, plasma can easily provide chemical or physical reactions which are difficult to approach by other ways. Also, processes using characteristics of plasma are widely used in several areas of industry due to the characteristic of plasma.

Actually, in modern industry, plasma application technology may be applied to many industrial fields using a material requiring high-function, high-intensity, and high-process. For example, the plasma application technology may be tried to surface processing, ion injection, depositing or removing organic or inorganic layer, cleaning, removing toxic material, disinfection for all sorts of materials in high-tech material industry, the electronics industry, or environmental industry. Also, since plasma processing technology is more advanced than conventional machine process technology, the plasma processing technology is used in a main apparatus manufacturing products and components in such fields of semiconductor, LCD, or MEMS, which require micro patterns.

However, since plasma has to be generated at high-temperature under vacuum atmosphere in conventional ways, there are many difficulties to apply the plasma processing technology to the real industrial fields.

First, when surrounding temperature is controlled to be high in order to generate plasma, a material such as a polymer which must be processed at a low temperature may receive a bad influence, and controlling the processing condition is

difficult in the process which has to be performed in a short time in order to minimize a temperature effect.

In addition, in order to generate plasma in a vacuum state, a closed system has to be formed. It is difficult to realize generating plasma in a vacuum state in consecutive operation or automated operation using a closed system. Also, it is a burden to purchase and maintain a high-priced vacuum system which is required to form a vacuum chamber.

Accordingly, if plasma can be continuously used at a room temperature under the atmospheric pressure, a consecutive and automated process may be realized, though it is difficult to be realized in a conventional closed system of vacuum low-temperature plasma, and a system of processing plasma may become simplified to be industrially applied. Also, if plasma processing at a low temperature under atmospheric pressure becomes included in industrial line, plasma processing may be performed in-line, thereby improving productivity.

For example, in order to realize information technology, MEMS, semiconductor, nano technology, bio technology, components having superior functionality, high-strength, high quality memory, high degree of integration are required. To manufacture the components, cleaning, as a basic process, is not subordinate technology and becomes core technology. However, a conventional wet type cleaning using chemicals, ultrasonic waves, and a water jet causes environmental pollution and consumes much of valuable water.

Currently, to solve the problem of the wet type cleaning, dry type processes such as various processes using ultraviolet rays, ozone, carbon dioxide, and plasma processing at a low temperature under atmospheric pressure are shown. When processing using ultraviolet rays, ozone, or plasma is performed, there are many problems happened such as overdischarging of polluted waste, delay of a processing, and limitation of processing function. Also, when processing using carbon dioxide is performed at very low temperature, there are many problems such as a high-priced system, a processing speed limit, and the limitation of processing function. Processing using plasma at a low temperature under atmospheric pressure may solve the problems of conventional wet and dry type cleaning processes.

In discharging plasma at normal temperature under atmospheric pressure,

atmospheric pressure increase of a system causes notable decrease of mean free path of the electron, thereby requiring extreme condition of electric discharge. Since electric discharging under atmospheric pressure, performed by conventional technology requires a very extreme electric field, a problem of requiring a huge voltage rather than a vacuum discharge is caused. Accordingly, technology for easily generating plasma at a low price in large quantities is required.

Corresponding to the requirement, most of apparatuses which are now being developed apply dielectric Barrier Discharge (DBD) method. DBD method in which more than one dielectric barrier is stuck to an electrode in order to discharge plasma has a merit of generating glow discharge which is possible generally in a vacuum. For reference, the atmospheric pressure means not only 1 atm (about 76cmHg) according to a scientific definition, but also equivalent pressure surrounding the scientific atmosphere pressure, which is similar thereto.

FIG. 1 is a schematic diagram illustrating a conventional DBD method.

Referring to FIG. 1, a plasma generation apparatus 10 includes a power electrode 20, an earth electrode 30, and a dielectric layer 40. The dielectric layer 40 is formed on a surface of the power electrode 10, opposite to the earth electrode 30. Radio frequency (RF) power having a predetermined frequency is applied to the power electrode 20, thereby generating plasma at a low temperature under atmospheric pressure between the power electrode 20 and the earth electrode 30. Reaction gas including an inert gas is provided to a space between the power electrode 20 and the earth electrode 30, thereby easily generating particles having high activity, such as ozone or radical. Since the temperature of the plasma generated below the power electrode 20 is relatively low, many kinds of materials, such as metal, plastic, glass, etc., can be processed by the plasma without thermal deformity and cleaning or forming an oxide layer on a surface of material under process, which passes through the power electrode 20 and the earth electrode 30.

Also, since the plasma generation apparatus 10 employing DBD method can discharge under atmospheric pressure, the plasma generation apparatus 10 is cheaper than a plasma generation apparatus employing vacuum discharge, is not limited in space, and can be employed in a serial process in-line or an automated process.

To generate plasma using DBD method, generally, a low-frequency source

lower than about 400KHz is applied at the power electrode 20. When a low-frequency source is used, since a voltage of a low-frequency source is higher than a voltage of a high-frequency source in the same power condition, plasma is easily generated in a low-frequency source. However, when a low-frequency source is used, since current is small and the density of generated plasma is low, plasma processing may be performed very slowly. Also, when material under process is a metal, an arc and charge damage of the material may be generated caused by charge storage. Furthermore, in an open space, glow plasma is difficult to be generated.

Compared to a low-frequency source, at a high-frequency source higher than 13,56MHz, a comparatively low voltage is kept in the same power condition, current flows at a high-frequency source approximately 10 to 100 times more than at a low-frequency source. Accordingly, when a high-frequency source is used, plasma having comparatively high density can be generated and processing speed can be notably improved.

However, when a high-frequency source is applied to the power electrode, power consumption for generating plasma, even if the plasma is processed on a very small area, is great. In addition, since the generated plasma is not stable, plasma may be removed when material under process is transferred. Also, when a metal is processed, an arc may be generated caused by high power.

FIG. 2 is a graph of a current-voltage characteristic curve illustrating characteristic of glow plasma.

Referring to FIG. 2, when normal glow plasma is generated, the current-voltage characteristic curve has two peaks at B and E. The greater a current difference between the two peaks B and E is, the more stable glow plasma is generated. When power is slowly increased from an initiate state A, current and voltage are increased and glow plasma is generated at the first peak B. Voltage between electrodes is rapidly decreased. Then, only current flowing is increased and voltage is kept constant during a predetermined section (C-D) even if power is increased. As described above, normal glow plasma is generated in a section in which voltage is constant. When the section is wide, stable plasma can be generated without an arc even if an environment variation occurs, for example, a conductive material passes between electrodes. Then, when more than a predetermined level of power is supplied, abnormal glow plasma is

generated (D-E). Voltage is decreased at the second peak E, and an arc occurs.

The current-voltage characteristic curve shown in FIG. 2 is an ideal curve and corresponds to a case of generating glow plasma in a vacuum. Accordingly, to generate glow plasma under atmospheric pressure in which variation factor of the surroundings is difficult.

[Table 1]

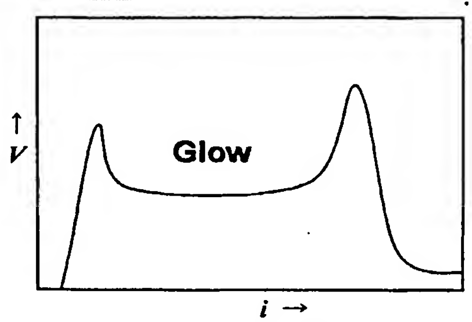
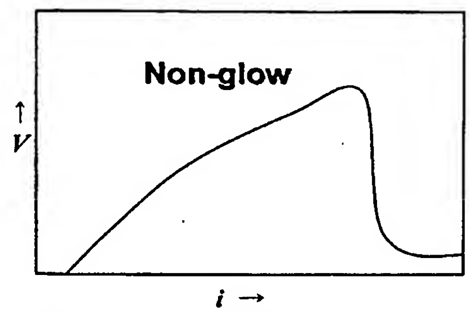
Glow plasma in a vacuum	**Conventional plasma under atmospheric pressure**
	
• Whole plasma is generated • An arc does not occur when material under process is conductive.	• Local plasma is generated • An arc may occur when material under process is conductive.

Table 1 illustrates current-voltage characteristic curves in order to compare two conditions with each other, in which when glow plasma is generated in a vacuum or under atmospheric pressure. As shown in Table 1, the current-voltage characteristic curve in which conventional plasma is formed under atmospheric pressure is different from the current-voltage characteristic curve in which plasma is formed in a vacuum. The curve for the conventional plasma under atmospheric pressure generally has one peak, and it is difficult to find a section in which normal glow plasma is formed. Even if the section in which normal glow plasma is formed exists, the section is too small to generate stable glow plasma. Also, when a metal passes adjacent to the power electrode, an arc immediately occurs to make plasma processing difficult.

As described above, a conventional technology of processing plasma under atmospheric pressure has problems -such as difficulty in generating glow plasma, instability of plasma, an arc occurrence of a metal under process, difficulty in generating wide area plasma, a limit of processing speed, difficulty in generating high-

density plasma. When material under process is made of a metal, the stability of plasma depends on a roughness of a surface, a shape, and a size of a pattern.

Disclosure of Invention

The present invention provides a plasma generation apparatus generating stable glow plasma.

The present invention also provides a plasma generation apparatus controlling freely generation and extinguishment of plasma.

The present invention also provides a plasma generation apparatus easily generating plasma over wide surface area.

The present invention also provides a plasma generation apparatus in which glow plasma can directly contact material under process when the surface of a metal is processed.

The present invention also provides a plasma generation apparatus that is not restricted in installation conditions of open space under atmospheric pressure, and can make plasma cleaning, ashing, etching, deposition, and other processes rapidly performed.

According to an aspect of the present invention, there is provided a plasma generation apparatus includes a power electrode, a first dielectric layer, an AP earth electrode, a second dielectric layer, a gas flow portion, and a power controller.

The power electrode is separated from material under process at a predetermined interval, and main plasma can be generated when RF power is sufficiently supplied to the power electrode. Generally, when material under process is a metal, main plasma can be generated without an additional MP earth electrode, but when material under process is not a metal, main plasma can be generated by an additional MP earth electrode. Also, when material under process is not conductive, the MP earth electrode contacts the material under process or is separated from the material under process at a predetermined interval.

The first dielectric layer formed of thermal resistance polymer such as silicon and polyimide or oxides such as alumina (Al_2O_3) and quartz (SiO_2) is provided between the power electrode and the material under process. Since the first dielectric layer is interposed between the power electrode and the material under process, occurrence of

an arc via the material under process is minimized and glow plasma is stably generated. However, even if the first dielectric layer exists, occurrence of an arc is not perfectly prevented. An arc may still occur when a metallic material passes adjacent to the power electrode.

Accordingly, the plasma generation apparatus can generate stable plasma without occurrence of an arc using auxiliary plasma when a metal is processed. For this, the AP earth electrode is disposed adjacent to the power electrode, and the second dielectric layer is provided between the power electrode and the AP earth electrode. Since an interval therebetween is narrow and small, auxiliary plasma can be generated using much less power than the power used in generating main plasma.

When the apparatus operates, auxiliary plasma is always generated and maintained by relatively small RF power supplied to the power electrode. Accordingly, when the power controller supplies large RF power in order to generate main plasma, main plasma is generated between the power electrode and the material under process. In this case, a plasma state is easily transmitted from auxiliary plasma, thereby rapidly generating main plasma.

According to experiments, since the apparatus using auxiliary plasma, a current-voltage characteristic curve illustrated in FIG. 2 is generated. Accordingly, as generating glow plasma in vacuum state, the current-voltage curve according to the present invention has a wide glow plasma area and two peaks under the atmospheric pressure. Namely, the apparatus can generate stable glow plasma and keep the close interval between the power electrode and the material under process as short such that luminous portion of the plasma can directly contact the material under process without an occurrence of an arc when a metal is processed.

Particularly, when a high-frequency of 13.56MHz is used, plasma of high density is generated such as to improve processing speed, but a state of main plasma is very unstable such as to be often extinguished at the middle of a process. However, when auxiliary plasma of low power is maintained in accordance with the present invention, since a plasma state is easily transmitted from auxiliary plasma, main plasma can be maintained and uniform plasma can be provided.

Also, since stable main plasma is maintained using auxiliary plasma, the apparatus uses smaller electric power for maintaining main plasma than conventional

plasma generation apparatus. Accordingly, the apparatus uses a low level of power and minimize power consumption.

A mixed gas for generating plasma is provided between the power electrode and the AP earth electrode via the gas flow portion while auxiliary plasma is maintained. A mixed gas for generating plasma may be formed of inert gas itself such as helium (He) or argon (Ar), or may be formed of inert gas and reaction gas in which a very small amount of oxide or nitrogen is mixed besides the inert gas. The mixed gas is provided, thereby maximizing an amount of active radical.

As described above, the power controller may control RF power supplied to the power electrode. Power of low level to generate auxiliary plasma may be always provided though main plasma is not generated, and a level of power is increased to generate main plasma processing the material under process. The power controller may include other functions besides supplying RF power. For example, when a high-frequency more than 13.56MHz is used, a matching box or other functions can be included in order to generate stable power.

In conventional processes using plasma at low temperature under atmospheric pressure, an arc occurs when a metal is processed, so, plasma is generated separating a power electrode from material under process in order to solve the problem. However, plasma can not contact the material under process and particles such as radical generated by plasma can reach to the material under process such as to processing speed is notably slow. However, the apparatus according the present invention can prevent an arc when a metal is processed, and the material under process is transported adjacently to the power electrode such that plasma directly contacts a metal material under process. Since plasma directly processes the material under process, material requiring high-workability and processing speed is notably increased.

According to another aspect of the present invention, there is provided a plasma generation apparatus includes a plurality of power electrodes, a plurality of AP earth electrodes, a dielectric layer, a gas flow portion, and a power controller. A plurality of the power electrodes and the AP earth electrodes are disposed in a row, auxiliary plasma is generated via each of the AP earth electrodes, auxiliary plasma is generated by a difference between the power electrode and the AP earth electrode, and auxiliary plasma is generated using a lower level of power than main plasma.

Since the power electrodes and the AP earth electrodes are disposed in a row, a plurality of plasma sources can be generated above the material under process or a path in which the material under process is transported. Plasma having a wide area can be generated between the power electrode and the material under process, using each of the plurality of plasma sources.

Generally, the power electrodes and the earth electrodes are formed in a panel shape and arranged in a row, and dielectric layers formed around the power electrodes or the earth electrodes to generate glow plasma under atmospheric pressure. The plasma generation units formed of the power electrode and the earth electrode are arranged parallel to face each other, thereby providing a sufficient amount of plasma and providing plasma under atmospheric pressure on a wide area. In the parallel-arrangement plasma generation apparatus, an MP earth electrode can be jointly used and material under process itself can be used as an earth.

According to another aspect of the present invention, there is provided a plasma generation apparatus includes a cylindrical power electrode, a dielectric layer, an AP earth electrode, a gas flow portion, and a power controller. The dielectric layer may cover the circumference of the cylindrical power electrode. The cylindrical power electrode is easily manufactured. The cylindrical power electrode is structurally supported by the dielectric layer, thereby being fixed without additional supporting elements. Also, the power electrode can be simply and perfectly insulated, and insulation destruction does not occur even if a strong electric field is suspended on the power electrode, thereby providing a relatively large amount of a reaction gas to generate a sufficient amount of plasma.

Brief Description of the Drawings

FIG. 1 is a configuration diagram illustrating a conventional dielectric barrier discharge (DBD) method;

FIG. 2 is a graph of current-voltage characteristic curve for illustrating the characteristic of glow plasma;

FIG. 3 is a configuration diagram of a plasma generation apparatus according to first embodiment of the present invention;

FIG. 4 is a configuration diagram illustrating plasma generation mechanism of

the plasma generation apparatus of the first embodiment of the present invention;

FIG. 5 is a configuration diagram of a plasma generation apparatus according to another embodiment of the present invention, similar to the first embodiment of the present invention;

FIG. 6 is a cross-sectional view of a plasma generation apparatus according to second embodiment of the present invention;

FIG. 7 is a perspective view of the plasma generation apparatus according to the second embodiment of the present invention;

FIG. 8 is a partial exploded view of an earth body of the plasma generation apparatus of the second embodiment of the present invention;

FIG. 9 is a cross-sectional view illustrating an operation process of the plasma generation apparatus of the second embodiment of the present invention;

FIG. 10 is a cross-sectional view of a plasma generation apparatus according to third embodiment of the present invention;

FIG. 11 is a cross-sectional view of a plasma generation apparatus according to fourth embodiment of the present invention;

FIG. 12 is a cross-sectional view illustrating a process in which main plasma operates in the plasma generation apparatus of the fourth embodiment of the present invention;

FIG. 13 is a cross-sectional view of a plasma generation apparatus according to another embodiment of the present invention, similar to the fourth embodiment of the present invention;

FIG. 14 is a configuration diagram of a plasma generation apparatus according to fifth embodiment of the present invention;

FIG. 15 is a configuration diagram illustrating plasma generation mechanism of the plasma generation apparatus of the fifth embodiment of the present invention;

FIG. 16 is a configuration diagram of a plasma generation apparatus according to another embodiment of the present invention, similar to the fifth embodiment of the present invention;

FIG. 17 is a cross-sectional view of a plasma generation apparatus according to sixth embodiment of the present invention;

FIG. 18 is a cross-sectional view illustrating an operation of plasma process of

the plasma generation apparatus according to the sixth embodiment of the present invention;

FIG. 19 is a cross-sectional view of a plasma generation apparatus according to another embodiment of the present invention, similar to the sixth embodiment of the present invention;

FIGS. 20 and 21 are cross-sectional views of plasma generation apparatuses according to other embodiments of the present invention, similar to the sixth embodiment of the present invention;

FIG. 22 is a cross-sectional view of a plasma generation apparatus according to seventh embodiment of the present invention;

FIG. 23 is a cross-sectional view of a plasma generation apparatus according to another embodiment of the present invention, similar to the seventh embodiment of the present invention;

FIG. 24 is a cross-sectional view of a plasma generation apparatus according to still another embodiment of the present invention, similar to the seventh embodiment of the present invention; and

FIG. 25 is a cross-sectional view of a plasma generation apparatus according to eighth embodiment of the present invention.

Best Mode for Carrying out the Invention

The present invention will now be described more fully with reference to the accompanying drawings, in which exemplary embodiments of the invention are shown. The invention may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein.

Embodiment 1

FIG. 3 is a configuration diagram of a plasma generation apparatus 100 according to first embodiment of the present invention, and FIG. 4 is a configuration diagram illustrating plasma generation mechanism of the plasma generation apparatus 100.

Referring to FIG. 3, the apparatus 100 includes a power electrode 110, a dielectric layer 120, a main plasma (MP) earth electrode 140, an auxiliary plasma (AP) earth electrode 130, a gas flow portion 150, and a power controller 160. The dielectric

layer 120 is divided into a first dielectric layer 122 interposed between the power electrode 110 and the MP earth electrode 140 and a second dielectric layer 124 interposed between the power electrode 110 and the AP earth electrode 130.

The power electrode 110 is formed a metal such as stainless steel or aluminum alloy and is electrically connected to the power controller 160. The power controller 160 may supply RF power to the power electrode 110, and the RF power supplied from the power controller 160 may be low-frequency power or high-frequency power depending on usage condition. Referring to FIG. 3, a voltage of low power only to generate auxiliary plasma is supplied from the power controller 160 and the interval between the power electrode 110 and the AP earth electrode 130 is very narrow and has a very small area, such as to auxiliary plasma is easily kept using a small voltage.

The first dielectric layer 122 and the second dielectric layer 124 are formed of aluminum, quartz, silicon, or ceramic and are in a single body to form the dielectric layer 120. The dielectric layer 120 which is an insulating material and formed around the power electrode 110 cuts off direct contact between the power electrode 110 and the MP earth electrode 140 and AP earth electrode 130 and prevents an arc from occurring between the power electrode 120 and the MP earth electrode 140 and AP earth electrode 130. In this case, the dielectric layer 120 is formed to a thickness of approximately 0.1 to 10mm.

The AP earth electrode 130 is disposed at a lower portion of the side of the power electrode 110, where is covered by the dielectric layer 120. The second dielectric layer 124 is interposed between the AP earth electrode 130 and the power electrode 110. The AP earth electrode 130 is disposed adjacent to the power electrode 110 with an interval approximately 0.1 to 20mm such that auxiliary plasma is generated even if a small voltage is supplied to the power electrode 110. Also, since the AP earth electrode 130 is disposed parallel with the power electrode 110 to face with each other, auxiliary plasma can be generated using small power and auxiliary plasma generated at this time is formed along the power electrode 110. Accordingly, auxiliary plasma is rapidly transmitted to main plasma through the entire area.

In order to forming a large amount of radicals and ions, mixed gas is provided to a space between the power electrode 110 and the AP earth electrode 130. The mixed gas includes inert gases such as helium (He) and argon (Ar). The inert gases

include a very small amount of reaction gas such as oxygen and nitrogen. Also, carbon, hydrogen, chlorine, ammonia, and methane may be included in the reaction gases so as to remodeling chemical characteristic of a surface when plasma processing is performed. The mixed gas is provided from the outside via the gas flow portion 150. The mixed gas is provided entirely and uniformly through the power electrode 110 and the AP earth electrode 130. The mixed gas provided through the power electrode 110 and the AP earth electrode 130 is dissociated by a strong electric field, thereby generating plasma.

The MP earth electrode 140 is disposed below the power electrode 110 and separated from the power electrode at a predetermined interval. The MP earth electrode 140 generates main plasma in response to RF power of the power electrode 110. When the power supplied to the power electrode 110 is increased more than a predetermined level of power, main plasma can be generated. When material under process is a metal, main plasma can be formed without the MP earth electrode 140. When material under process is not a metal, the MP earth electrode 140 is required to form an electric field. Also, the MP earth electrode 140 may be keep contact with nonmetal material under process, according to cases, the MP earth electrode 140 may be separated from material under process at a small interval not into contact with each other.

An MP earth electrode is for forming an electric field. If the MP earth electrode can form an earth corresponding to a power electrode, there is no restriction on the form or a position of an earth. For example, according to another embodiment of the present invention, when material under process continuously moves during being processed, a conveyer belt itself can keep a state of an earth as an effective earth electrode.

Referring to FIG. 4, material under process M is disposed between the power electrode 110 and the MP earth electrode 140. In this case, the power controller 160 supplies RF power whose power is increased to the power electrode 110. In response to increase of power of RF power, glow plasma is generated between the power electrode 110 and the material under process M.

Auxiliary plasma is always formed between the power electrode 110 and the AP earth electrode 130. Accordingly, when main plasma is generated, a state of

plasma can be easily transmitted from auxiliary plasma to main plasma. The plasma generation apparatus 100 according to the first embodiment of the present invention can generates plasma which is more stable and less loss of power than plasma generated by conventional plasma generation apparatuses.

Since electric power for keeping auxiliary plasma is slight comparing to electric power for keeping main plasma, auxiliary plasma can be kept without extinguishment when the material under process M is processed. Accordingly, if a state of main plasma becomes not stable due to instability of supply voltage, a stable plasma state can be transmitted at any time from auxiliary plasma to main plasma, there keeping main plasma in a stable state.

FIG. 5 is a configuration diagram of a plasma generation apparatus according to another embodiment of the present invention, similar to the first embodiment of the present invention.

Referring to FIG. 5, comparing to the first embodiment of the present invention, a plasma generation apparatus 101 of FIG. 5 further includes a capacitance earth electrode 132 and a third dielectric layer 126 formed on the surface of the capacitance earth electrode 132. The capacitance earth electrode 132 forms a capacitance in response to RF power supplied from the power controller 160 and assists in forming stable plasma using RF power.

The capacitance earth electrode 132 and the AP earth electrode 130 may be formed in a single body, and the power electrode 110 and an earth body may be formed in a shape of a flat panel to form a flat panel plasma generation apparatus.

Embodiment 2

FIG. 6 is a cross-sectional view of a plasma generation apparatus 200 according to a second embodiment of the present invention, FIG. 7 is a perspective view of the plasma generation apparatus 200, and FIG. 8 is a partial exploded view of an earth body of the plasma generation apparatus 200.

Referring to FIGS. 6 through 8, the plasma generation apparatus 200 includes a power electrode 210, a dielectric layer 220, an MP earth electrode 240, an AP earth electrode 230, a capacitance earth electrode 232, a gas flow portion 250, and a power controller 260. The AP earth electrode 230 and the capacitance earth electrode 232 are formed of stainless steel or aluminum alloy and in a single body to form an earth body

235.

The AP earth electrode 230 is disposed at the bottom of the earth body 235, and an end of the AP earth electrode 230 is separated from the power electrode 210 on which the dielectric layer 220 is formed at a small interval. The interval between the AP earth electrode 230 and the power electrode 210 has a small size and is formed vertical to a transportation path of the material under process M. Accordingly, auxiliary plasma can be formed widely to cover the entire width of the material under process M.

The material under process M is continuously transferred between the power electrode 210 and the MP earth electrode 240 by a transfer roller. The plasma generation apparatus 200 generates main plasma when a portion of the material under process M, which will be processed, is passed, thereby continuously or discontinuously performing a plasma process.

The power electrode 210 is formed of stainless steel or aluminum alloy and in a shape of a flat panel. The power electrode 210 is electrically connected to the power controller 260 via a coaxial cable terminal 212, and RF power is supplied to the power electrode 210 by the power controller 260.

The power controller 260 includes an impedance matching box 262, and high-frequency power is transferred to the power electrode 210 via the matching box 262. Since the power controller 260 supplies power to generate auxiliary plasma and an interval between the power electrode 210 and the AP earth electrode 230 is very narrow and small, auxiliary plasma is easily kept using small power.

Table 2 illustrates discharge sustenance power to maintain auxiliary plasma and discharge maintenance power to maintain main plasma according to the area and length in which plasma is generated. Conditions below are for generating glow plasma. According to the conditions, auxiliary plasma is maintained using less than 50% power for maintaining main plasma.

[Table 2]

Area of plasma	10 cm^2		20 cm^2		60 cm^2		130 cm^2	
Length of plasma	100 mm		200 mm		600 mm		1300 mm	
Type of plasma	auxiliary	main	auxiliary	main	auxiliary	main	auxiliary	main
Discharge sustenance power	10 W	25 W	22 W	45 W	68 W	140 W	150 W	350 W
Sort of plasma	glow	glow	glow	glow	glow	glow	glow	glow

* conditions for generating plasma: used gas = Ar / height of plasma = 3 mm

The dielectric layer 220 is formed of alumina, quartz, silicon, or ceramic. The dielectric layer 220 is formed around the power electrode 210 to insulate the power electrode 210 from directly contacting with the peripheral earth electrodes. In this case, the dielectric layer 220 is formed to a thickness of approximately 0.1 to 10mm. The dielectric layer 220 corresponds to the first through third dielectric layers 122 to 126 of the first embodiment of the present invention, which are formed in a single body. The power electrode 210 can be inserted in the dielectric layer 220, or the dielectric layer 220 can be applied to or vapor deposited on the surface of the power electrode 210.

The earth body 235 is formed in a shape of a flat panel corresponding to the power electrode 210 and includes the AP earth electrode 230 for generating auxiliary plasma and the capacitance earth electrode 232 for forming a capacitance. Also, the gas flow portion 250 is formed in the earth body 235. Mixed gas flowing from outside for generating plasma passes through the gas flow portion and uniformly spreads between the AP earth electrode 220 and the power electrode 210. The earth body 235 is located on the power electrode 210, thereby forming a single plasma generation unit.

The gas flow portion 250 includes a first flow path 252, a second flow path 254 connected to the first flow path 252 and formed parallel with the power electrode 210, a flow chamber 256 formed between the power electrode 210 and the AP earth electrode 230, and a plurality of orifices 258 connecting the second flow path 254 and the flow chamber 256. Referring to FIGS. 6 through 8, a hole is formed in the earth body 235, thereby forming the first flow path 252 and the second flow path 254 in the earth body 235, and the earth body 235 is cut along the second flow path 254 to form the flow chamber 256. The orifices 258 are formed such as to uniformly spread mixed gas in

the flow chamber 256.

Accordingly, the mixed gas enters the earth body 235 via the first flow path 252 and is uniformly spread to the orifices 258 through the second flow path 254. The mixed gas having passed the orifices 258 is entirely spread via the flow chamber 256 along the power electrode 210 and the AP earth electrode 230. The spread read mixed gas assists generation of auxiliary plasma or main plasma in respective positions.

As described above, since the AP earth electrode 230 has to generate auxiliary plasma using only a small power, the AP earth electrode 230 is disposed adjacent to the power electrode 210 at an interval of 0.1 to 20mm and the height of the AP earth electrode 230 may be narrow to reduce a contact area in which the AP earth electrode 230 contacts with the power electrode 210. Also, since the AP earth electrode 230 is disposed parallel with the power electrode 210, a state of plasma can be quickly and entirely transmitted from auxiliary plasma to main plasma.

The MP earth electrode 240 is disposed below the power electrode 210 and separated from the power electrode 210 at a predetermined interval. The MP earth electrode 240 generates main plasma in response to RF power of the power electrode 210. When the power supplied to the power electrode 210 is increased more than a predetermined level of power, a strong electric field is formed between the power electrode 210 and the MP earth electrode 240, thereby generating main plasma.

FIG. 9 is a cross-sectional view illustrating an operation process of the plasma generation apparatus of the second embodiment of the present invention.

Referring to FIG. 9, main plasma is formed between the power electrode 210 and the MP earth electrode 240. Auxiliary plasma is formed between the power electrode 210 and the AP earth electrode 230.

Main plasma is glow plasma. The material under process M is transferred through the power electrode 210 and the MP earth electrode 240 and plasma processed widely. For example, there is cleaning or oxide layer forming in a plasma process. Also, since auxiliary plasma is always formed, a plasma state can be easily transmitted to main plasma to initially generate and continuously maintain main plasma.

Accordingly, a worker who performs plasma processing can generate and extinguish main plasma at any time when he wants, thereby performing precision plasma process at a normal temperature under atmospheric pressure. Since a state of

plasma can be easily transmitted from auxiliary plasma to main plasma when main plasma is generated, plasma which is much stabler and has a less electric loss can be generated.

Embodiment 3

FIG. 10 is a cross-sectional view of a plasma generation apparatus 300 according to third embodiment of the present invention.

Referring to FIG. 10, the plasma generation apparatus 300 includes power electrodes 310, dielectric layers 320, MP earth electrodes 340, AP earth electrodes 330, capacitance earth electrodes 332, a gas flow portion, and a power controller 360. The power electrodes 310 and the dielectric layers 320 are formed at the front and rear of the plasma generation apparatus 300. An earth body 335 including the AP earth electrodes 330 and the capacitance earth electrode 332 is interposed between the power electrodes 310 to be united to each other. The earth body 335 is formed of stainless steel or aluminum alloy, and the gas flow portion is formed in the earth body 335.

The AP earth electrodes 330 are formed respectively at the both side of the bottom of the earth body 335. The end of the AP earth electrode 330 is separated from the power electrode 310 surrounded by the dielectric layer 320 at a small interval. Accordingly, auxiliary plasma is formed widely at the both side of the bottom of the earth body 335. Also, auxiliary plasma can be formed widely to doubly cover the entire material under process M.

The power electrodes 310 are formed in a shape of a flat panel and disposed at the both side of the earth body 335, respectively. The power electrode 310 is formed of stainless steel or aluminum alloy and electrically connected to the power controller 360 via a coaxial cable terminal 312. RF power is supplied to the power electrode 310 by the power controller 360.

Since the power controller 360 supplies a predetermined level of power to generate auxiliary plasma and an interval between the power electrode 310 and the AP earth electrode 330 is very narrow and small, auxiliary plasma is easily maintained using only small power. Of course, even if auxiliary plasma is formed, main plasma can be formed when RF power is increased. Auxiliary plasma can be sufficiently maintained using less than 50% of power to maintain main plasma, as illustrated in Table 2.

The dielectric layer 320 is formed of alumina, quartz, silicon, or ceramic. The dielectric layer 320 is an insulating body formed around the power electrode 310 to insulate the power electrode 310 from directly contacting with the peripheral earth electrodes.

The gas flow portion is formed in the earth body 335. Mixed gas flowing from outside passes through the gas flow portion and uniformly spreads between both of the AP earth electrodes 320 and the power electrodes 310. The gas flow portion is connected to a first flow path 352, second flow paths 354 connected to the first flow path 352 and formed at the both side of the earth body 335 parallel to the power electrodes 310, respectively, inflow chambers 356 formed respectively between the power electrode 310 and the AP earth electrode 320, and a plurality of orifices 358 connecting the second flow path 354 and the inflow chamber 356. Referring to FIG. 10, the first flow path 352 is branched off toward the second flow path 354 and the inflow chambers 356 are formed at the both side of the earth body 335 along the second flow path. Also, the orifices 358 are formed to uniformly spread mixed gas over the inflow chamber 356 via the same.

Accordingly, mixed gas enters inside the earth body 335 via the first flow path 352 and uniformly distributed to the orifices 358 through the second flow path 354. The mixed gas passing through the orifices 358 is distributed entirely along between the power electrode 310 and the AP earth electrode 330 via the inflow chamber 356. The distributed mixed gas assists generation of auxiliary plasma or main plasma in respective positions.

The MP earth electrode 340 is disposed below the power electrodes 310 and separated from the power electrodes 310 at a predetermined interval. The MP earth electrode 340 generates main plasma in response to RF power of the power electrode 310. When the power supplied to the power electrode 310 is increased more than a predetermined level of power, a strong electric field is formed between the power electrode 310 and the MP earth electrode 340 and a state of plasma is rapidly transmitted from auxiliary plasma to main plasma, thereby directly generating main plasma and maintaining a stable state of plasma.

Embodiment 4

FIG. 11 is a cross-sectional view of a plasma generation apparatus 201

according to fourth embodiment of the present invention, and FIG. 12 is a cross-sectional view illustrating a process in which main plasma operates in the plasma generation apparatus 201. The plasma generation apparatus 201 similar to the plasma generation apparatus 200 according to the second embodiment of the present invention except that power electrodes 210 are disposed parallel to earth bodies 235. The power electrode 210 and the earth body 235 can be described referring to the description of the second embodiment and FIGS. 6 through 9. Therefore, in the description of the fourth embodiment, a part overlapping the description of the second embodiment will be omitted.

Referring to FIG. 11, the plasma generation apparatus 201 includes two power electrodes 210, dielectric layers 220 formed on the surface of the respective power electrodes 210, earth bodies 235 disposed adjacent to the respective power electrodes 210, gas flow portions 250 formed in the earth bodies 235, and a power controller 260. Also, the earth body 235 includes an AP earth electrode 230 and a capacitance earth electrode 232. The AP earth electrode 230 and the capacitance earth electrode 232 are formed in a single body and electrically connected to each other.

The power electrode 210 is formed in a shape of a flat panel of stainless steel or aluminum alloy. The power electrode 210 is electrically connected to the power controller 260 via a coaxial cable terminal. RF power is supplied from the power controller 260 to the power electrode 210. Since the power controller 260 supplies a predetermined level of power to generate auxiliary plasma and an interval between the power electrode 210 and the AP earth electrode 230 is very narrow and small, auxiliary plasma is easily maintained using only small power. Also, since the AP earth electrode 230 is disposed parallel to the power electrode 210, a state of plasma can be quickly and entirely transmitted from auxiliary plasma to main plasma.

The earth body 235 is formed in a shape of a flat panel, corresponding to the power electrode 210. The gas flow portion 250 is formed in the earth body 235. Mixed gas flowing from the outside passes through the gas flow portion 250 and is distributed between the AP earth electrode 220 and the power electrode 210.

The power electrode 210 and the earth body 235 are alternately disposed parallel to the each other. Intervals between the AP earth electrodes 230 and the power electrodes 210 are disposed parallel to each other, forming a plurality of columns.

When a level of power supplied from the power controller 260 to the power electrode 210 is increased, main plasma is formed between the power electrode 210 and material under process. In this case, main plasma receives a state of plasma from auxiliary plasma and rapidly spreads.

Referring to FIG. 12, since the power electrodes 210 are disposed forming a plurality of columns and main plasma is formed at each of the power electrodes 210, amount of plasma required in plasma processing is increased and plasma reaction occurs multiple material under process at the same time.

Although the power electrodes 210 and the earth bodies 235 make a pair and are disposed in two columns, respectively, in FIGS 11 and 12, in another embodiment of the present invention, the number of columns of the power electrode 210 and the earth bodies 235 may be increased according to the sort or size of material under process.

FIG. 13 is a cross-sectional view of a plasma generation apparatus according to another embodiment of the present invention, similar to the fourth embodiment of the present invention.

Referring to FIG. 13, such that a state of a reaction gas of mixed gas can be transmitted to a state of plasma, a process of igniting the reaction gas at a beginning of a plasma process. For this, a discharge needle 270 and an igniter 275 electrically connected to the discharge needle 270 are disposed between the AP earth electrode 230 and the dielectric layer 220. A lead wire connecting the discharge needle 270 to the igniter 275 include a gap 272 having a predetermined space.

Instant high voltage can be supplied to the discharge needles 270 using the igniters 275. A voltage difference, which is required for generating plasma at a beginning of plasma processing, can occur using the discharge needles 270 and the igniters 275. The reaction gas is ignited by the instant high voltage, thereby generating auxiliary plasma. Accordingly, a power controller of a plasma generation apparatus needs not to be loaded for a high initiating voltage, and power consumption is kept as low.

The discharge needles 270 are connected respectively to the igniters 275 to be separated at a predetermined interval by the gaps 272. The discharge needles 270 are formed of a metal having a high conductivity and high arc resistance, such as platinum

or tungsten. An induced electromotive force is generated between the power electrode 210 and the AP earth electrode 230. The gap 272 is formed between the discharge needle 270 and the igniter 275, thereby preventing an electromotive current from being inverse biased from the discharge needle 270 to the igniter 275.

Embodiment 5

FIG. 14 is a configuration diagram of a plasma generation apparatus 400 according to fifth embodiment of the present invention, and FIG. 15 is a configuration diagram illustrating plasma generation mechanism of the plasma generation apparatus 400.

Referring to FIG. 4, the plasma generation apparatus 400 includes a power electrode 410, a dielectric layer 420, an MP earth electrode 440, an AP earth electrode 430, a gas flow portion 450, and a power controller 460.

The power electrode 410 is form in a shape of a cylinder formed of stainless steel or aluminum alloy and electrically connected to the power controller 460. RF power is supplied to the power electrode 410 by the power controller 460. Low-frequency power or high-frequency power may be supplied depending on purpose of user. Since the power controller 460 supplies a predetermined level of power to generate auxiliary plasma and an interval between the power electrode 410 and the AP earth electrode 430 is very narrow and small, auxiliary plasma is easily maintained using only small power.

According to the fifth embodiment of the present invention, the power electrode 410 is cylindrical, and the axle is formed straightforwardly. However, a power electrode can be curved concavely or convexly and the surface of a power electrode can include a partially curved portion depending on a shape of material under process. In order to have a curved surface, a dielectric layer covering the circumference of a power electrode may be formed of a flexible and soft such as silicon or polyimide.

The dielectric layer 420 formed of alumina, quartz, silicon, or ceramic is formed around the power electrode 410. The dielectric layer 420 is an insulating body formed on the power electrode 410 to insulate the power electrode 410 from directly contacting the earth electrodes. Also, the dielectric layer 420 prevent occurrence of an arc when main plasma is generated in order to assist forming glow discharge between the power electrode 410 and material under process M. In this case, the dielectric

layer 420 is formed to have a thickness of approximately 0.1 to 10mm.

The AP earth electrode 430 is disposed adjacent to the bottom of the side of the power electrode 410 covered by the dielectric layer 420. Since the AP earth electrode must be able to generate when a small power is supplied to the power electrode 410, the auxiliary plasma is disposed adjacent to the power electrode 410 at an interval of 0.1 to 20mm. Also, since the AP earth electrode is disposed parallel to the power electrode 410, auxiliary plasma is formed at great length along the power electrode 410. Therefore, a state of plasma can be rapidly transmitted from auxiliary plasma to main plasma over the entire part.

A reaction gas is provided to a space between the power electrode 410 and the AP earth electrode 430 in order to form a large amount of ozone and radical ions. The reaction gas may be an inert gas such as helium or argon or a gas in which an inert gas mixed with a very small amount of oxygen or nitrogen. The reaction gas is provided via the gas flow portion 450 from the outside to a space between the electrodes and along the power electrode 410 and the AP earth electrode 430 to be provided toward the entire. The reaction gas provided to the space between the power electrode 410 and the AP earth electrode 430 is dissociated by a strong electric field, thereby generating plasma from the reaction gas.

The MP earth electrode 440 is disposed below the power electrode 410 and separated from the power electrode 410 at a predetermined interval. The MP earth electrode 440 generates main plasma in response to RF power of the power electrode 410. When the power supplied to the power electrode 410 is increased more than a predetermined level, main plasma can be generated. When material under process is a metal, main plasma can be generated without the MP earth electrode 440. When material under process is not a metal, the MP earth electrode 440 is required to form an electric field. There is no restriction on an earth form or an earth position of a MP earth electrode, which can form an earth corresponding to a power electrode. For example, according to another embodiment of the present invention, when material under process is continuously move during plasma processing, a conveyer belt itself may be used for an MP earth electrode. A conveyer belt can keep an earth, thereby being an effective earth electrode.

Referring to FIG. 15, material under process M is disposed between the power

electrode 410 and the MP earth electrode 440. In this case, the power controller 460 supplies RF power whose level is increased, thereby generating glow plasma between the power electrode 410 and the material under process M.

Auxiliary plasma is always formed between the power electrode 410 and the AP earth electrode 430. Accordingly, when main plasma is generated, a state of plasma of auxiliary plasma can be easily transmitted to main plasma. The plasma generation apparatus 400 can generate plasma which is more stable and has a less loss than conventional plasma generation apparatuses.

Since the power maintaining auxiliary plasma is much smaller than the power maintaining main plasma, auxiliary plasma can be maintained as a stable plasma state without extinguishment during the material under process M is processed. Accordingly, if a state of main plasma is not stable due to instability of supplying power, the state of stable auxiliary plasma can be transmitted to the main plasma at any time, thereby maintaining main plasma as a stable state without extinguishment.

FIG. 16 is a configuration diagram of a plasma generation apparatus 401 according to another embodiment of the present invention, similar to the fifth embodiment of the present invention.

Referring to FIG. 16, the plasma generation apparatus 401 further includes a capacitance earth electrode 432 than the plasma generation apparatus 400. The capacitance earth electrode 432 forms a capacitance in response to RF power supplied from the power controller 450 and assists in forming stable plasma using RF power.

The capacitance earth electrode 432 can equip a power electrode 410 and a dielectric layer 420 by containing the power electrode 410 and the dielectric layer 420. The AP earth electrode 430 and the capacitance earth electrode 432 may be formed in a single body as an earth body.

<u>Embodiment 6</u>

FIG. 17 is a cross-sectional view of a plasma generation apparatus 500 according to sixth embodiment of the present invention, and FIG. 18 is a cross-sectional view illustrating an operation process of the plasma generation apparatus 500.

Referring to FIGS. 17 and 18, the plasma generation apparatus 500 includes a power electrode 510, a dielectric layer 520, an MP earth electrode 540, an AP earth electrode 530, a capacitance earth electrode 532, a gas flow portion 550, and a power

controller 560. The AP earth electrode 530 and the capacitance earth electrode 532 are formed of stainless steel and aluminum alloy and in a single body to form an earth body 535. A cylindrical hole is formed at the bottom vertically to a transportation path of material under process M. The lower end of the hole is partially opened such as to expose a portion of the dielectric layer 520 from the bottom of the earth body 535 when the power electrode 510 and the dielectric layer 520 are inserted together into the hole. Accordingly, plasma can be uniformly formed over widely area when main plasma is generated by the power electrode 510.

The material under process M is consecutively transferred by a roller R between the earth body 535 and the MP earth electrode 540. The plasma generation apparatus 500 can consecutively perform plasma processing by generating main plasma at needed positions.

The power electrode 510 is formed in a shape of a cylinder and formed of stainless steel or aluminum alloy. The power electrode 510 is electrically connected to the power controller 560, and the power controller 560 may supply RF power to the power electrode 510.

The power controller 560 includes an impedance matching box 562, and high-frequency is transmitted to the power electrode 510 via the matching box 562. Since the power controller 560 supplies the power to generate auxiliary plasma and an interval between the power electrode 510 and the AP earth electrode 530 is very narrow and small, auxiliary plasma can be easily maintained using a small power.

As illustrated in Table 2, auxiliary plasma can be sufficiently maintained using a power less 50% of the power used to maintain main plasma.

The dielectric layer 520 is formed of alumina, quartz, silicon, or ceramic. The dielectric layer 520 is an insulating body formed around the power electrode 510 to insulate the power electrode 510 from directly contacting to the earth electrodes. In this case, the dielectric layer 520 is formed to a thickness of approximately 0.1 to 10mm.

The dielectric layer 520 is formed in two methods in which a hollow cylinder is molded and the power electrode 510 in a cylindrical shape is inserted into the dielectric layer 520, or the dielectric layer 520 is vapor deposited on the surface of the power electrode 510. According to the above, the cylindrical dielectric layer 520 covers the circumference of the power electrode 510 without additional supporting elements,

which is a simple configuration can perfectly insulate the power electrode 510. Therefore, if a strong electric field is suspended on the power electrode 510, there is no insulation destruction such as to supply a large amount of reaction gas to generate a sufficient amount of plasma.

The earth body 535 is an earth electrode including the AP earth electrode 530 disposed adjacent to the power electrode to generate auxiliary plasma and the capacitance earth electrode 532 partially containing the power electrode 510 and forming a capacitance. The gas flow portion 550 is formed in the earth body 535, and a reaction gas flowing from the outside is transferred via the gas flow portion and is uniformly distributed a space between the AP earth electrode 520 and the power electrode 510.

The gas flow portion 550 includes a first flow path 552 in which a reaction gas flow from the outside, a second flow path 554 connected to the first flow path 552 and formed parallel to the power electrode 510, an inflow chamber 556 formed between the power electrode 510 and the AP earth electrode 520, and a plurality of orifices 558 connecting the second flow path 554 and the inflow chamber 556. A reaction gas is transferred to the earth body 535 via the first flow path 552 and uniformly distributed to the orifices 558 via the second flow path 554. The reaction gas passing through the orifices 558 is entirely distributed along a space between the power electrode 510 and the AP earth electrode via the inflow chamber 556. The distributed reaction gas assists in generating auxiliary plasma or main plasma at respective positions.

As described above, the AP earth electrode 530 is disposed adjacent to the power electrode 510 at an interval of approximately 0.1 to 20mm in order to generate plasma using a small amount of power. Also, since the AP earth electrode 530 is disposed parallel to the power electrode 510, auxiliary plasma can be rapidly and widely transmitted to main plasma over the entire area.

The MP earth electrode 540 is disposed below the power electrode 510 and separated from the power electrode 510 at a predetermined interval. The MP earth electrode 540 generates main plasma in response to RF power of the power electrode 510. When the power supplied to the power electrode 510 is increased more than predetermined power, a strong electric field is formed between the power electrode 510 and the MP earth electrode 540, thereby generating main plasma by the strong electric

field.

Referring to FIG. 18, main plasma is formed between the power electrode 510 and the MP earth electrode 540. Of course, auxiliary plasma is formed together with main plasma between the power electrode 510 and the AP earth electrode 530.

Main plasma is glow plasma. Material under process goes through a plasma process such as cleaning or forming an oxide layer widely over the entire area while being transferred between the power electrode 510 and the MP earth electrode 540. Also, since auxiliary plasma is always formed, a state of plasma can be easily transmitted to main plasma and initially generating or continuously maintaining main plasma is kept stable.

Accordingly, a worker performing plasma process can generate or extinguish main plasma at any time he wants, thereby performing plasma process at a normal temperature under atmospheric pressure. Since a state of auxiliary plasma can be easily transmitted when main plasma is generated, plasma which is more stable and has a less loss of electric power can be generated.

FIG. 19 is a cross-sectional view of a plasma generation apparatus according to another embodiment of the present invention, similar to the sixth embodiment of the present invention.

Referring to FIG. 19, an earth body 535 is extended toward the transfer direction of material under process, a plurality of cylindrical holes are formed arranged in a row in the earth body 535, and a power electrode 510 and a dielectric layer 520 are inserted into each of holes. An AP earth electrode 530, a capacitance earth electrode 532, and a gas flow portion 550 are formed around each of the power electrodes 510. This is for mass plasma process, thereby performing stable plasma process over wide area. Also, a reaction gas flowing into each of the power electrodes 510 is changed differently, thereby changing differently characteristics of plasma process performed at each of the power electrodes 510.

FIGS. 20 and 21 are cross-sectional views of plasma generation apparatuses according to other embodiments of the present invention, similar to the sixth embodiment of the present invention.

Referring to FIG. 20, two earth bodies 535 are disposed top and bottom facing each other. A power electrode 510 and a dielectric layer 520 are inserted into each of

the earth bodies 525, and an AP earth electrode 530, a capacitance earth electrode 532, and a gas flow portion 550 are formed around the power electrode, as the same as the sixth embodiment of the present invention.

Since the two plasma generation apparatuses are disposed top and bottom, both sides of material under process passing through a space between the two apparatuses can be plasma processed. Of course, as described above, plasma process on both sides is changed differently from each other, thereby performing manufacturing process different from each other on both sides.

Referring to FIG. 21, the plasma generation apparatus of FIG. 19 is disposed top and bottom facing each other, and both sides of material under process passing through a space between the two apparatuses can be plasma processed.

Embodiment 7

FIG. 22 is a cross-sectional view of a plasma generation apparatus 600 according to seventh embodiment of the present invention.

Referring to FIG. 22, the plasma generation apparatus 600 includes a power electrode 610, a dielectric layer 520, an MP earth electrode 540, an AP earth electrode 530, a capacitance earth electrode 532, a gas flow portion 550, and a power controller 560. The AP earth electrode 530 and the capacitance earth electrode 532 are formed stainless steel or aluminum alloy and in a single body to form an earth body 535. Other components besides the power electrode 610 are actually the same as the components of the former embodiments such as to refer to the description and FIGS of the former embodiments.

The outside diameter of the power electrode 610 is formed smaller than the inside diameter of the dielectric layer 520, and an interval is provided between the power electrode 610 and the dielectric layer 520. According to this configuration, even if the power electrode 610 is thermally expanded during process, the dielectric layer 520 can receive the thermal expansion by the interval, thereby preventing the dielectric layer 520 from deterioration.

FIG. 23 is a cross-sectional view of a plasma generation apparatus according to another embodiment of the present invention, similar to the seventh embodiment of the present invention.

Referring to FIG. 23, grooves 612 are vertically formed on the surface of a

power electrode 610 in a shape of a cylinder, and an uneven portion formed by the grooves 612 is to face material under process. Electric charges are concentrated into the end of the uneven portion, thereby accelerating and strengthening the formation of an electric field.

FIG. 24 is a cross-sectional view of a plasma generation apparatus according to still another embodiment of the present invention, similar to the seventh embodiment of the present invention.

Referring to FIG. 24, a discharge needle 670 and an igniter electrically connected to the discharge needle 670 are disposed between the AP earth electrode 530 and the dielectric layer 520. A lead wire connecting the discharge needle 670 to the igniter 675 includes a gap 672 having a predetermined space.

High voltage is instantly supplied to the discharge needle 670 by the igniter 675 such as to ignite a reaction gas using the igniter 675 at the beginning of ignition of process. Power consumption can be decreased via ignition by the igniter 675 because high-frequency power supplied by a power controller does not require to load high initiation voltage.

Also, the discharge needle 670 is connected to the igniter 675 at a predetermined interval caused by the gap 672 such that induced electromotive current is prevented from being inversely biased from the discharge needle to the igniter 675 by induced electromotive force generated between the power electrode 610 and the AP earth electrode 530.

Embodiment 8

FIG. 25 is a cross-sectional view of a plasma generation apparatus according to eighth embodiment of the present invention.

Referring to FIG. 25, the plasma generation apparatus includes a power electrode 510, a dielectric layer 520, an MP earth electrode 540, AP earth electrodes 530, a capacitance earth electrode 532, gas flow portions 550, and a power controller 560, and the AP earth electrodes 530 and the gas flow portions 550 are disposed respectively in the both sides of the power electrode 510. Also, the AP earth electrodes 530 and the capacitance earth electrodes 532 are formed of stainless steel or aluminum alloy and in a single body to form an earth body 535.

Both of the AP earth electrodes 530 share the power electrode 535, and the

apparatus can be used without bias of power. Also, the flow of a gas flowing front and rear is opposite, thereby easily responding to the material under process required to be processed in a predetermined direction.

The power electrode 510 is formed in a shape of a cylinder of stainless steel or aluminum alloy. The power electrode 510 is electrically connected to the power controller 560, and RF power can be supplied to the power electrode 510 by the power controller 560.

The power to generate auxiliary plasma is basically supplied from the power controller 560, and auxiliary plasma can be easily maintained using a small power.

The dielectric layer 520 may be formed in a shape of a cylinder such that the power electrode 510 in a cylindrical shape can be inserted into the dielectric layer 520, or the dielectric layer 520 may be applied or vapor deposited on the surface of the power electrode 510. Therefore, the dielectric layer 520 in a cylindrical shape can cover the circumference of the power electrode 510 without additional supporting elements such as to perfectly insulate the power electrode 510. Accordingly, even if a strong electric field is suspended on the power electrode 510, there is no insulation destruction such as to provide a relatively large amount of reaction gas to generate plasma.

Industrial Applicability

As described above, the plasma generation apparatus can generate plasma at low temperature under the atmospheric pressure and provide a stable state of plasma using auxiliary plasma. When plasma discharge maintenance is not uniform caused by sample transportation or inflow of external gas and unstable high-frequency is used, auxiliary plasma functions as a stable plasma source, thereby generating stable glow plasma which can be uniformly applied on wide area in spite of sample transportation or inflow of unexpected external gas.

Also, a worker can rapidly generate or extinguish plasma according to the purpose of the worker using auxiliary plasma in order to precision plasma process.

Also, the plasma generation apparatus is not restricted by installation condition, thereby rapidly performing plasma cleaning and other processing via in-line consecutive process.

On the other hand, since a plurality of power electrodes and AP earth electrodes can be formed, the capacity of the plasma generation apparatus can be easily increased and the control of the width is unrestricted.

Also, since the inside diameter of a dielectric layer is formed larger than the outside diameter of a power electrode, thermal expansion of a power electrode is safely received. Since uneven portion is formed on the periphery of a power electrode, the formation of an electric field can be accelerated and strengthened in the same condition. Also, a discharge needle is disposed between a power electrode and an AP earth electrode and an igniter is connected to the discharge needle in order to initially ignite at the AP earth electrode, thereby reducing power consumed in initially igniting.

As described above plasma at low temperature under the atmospheric pressure can contribute to cleaning, ashing, etching, depositing, or other process of semiconductor wafers, LCD glass products, lead frames, PCBs, metal sheets, light guide panels, fibers, silicone, rubber, polymers, regardless of metal or nonmetal. Also, an organic ingredient of a sample can be processed in-line using activity of plasma, and quality of products can be improved without thermal deterioration of material under process because of low temperature characteristic of plasma.

Further, from now on, technology of generating plasma at low temperature under atmospheric pressure can be applied to not only industrial development of semiconductor and PCB, but also processing on the surface of plastic products and glass products, disinfecting medical instruments and groceries.

While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.